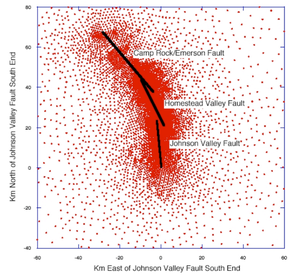
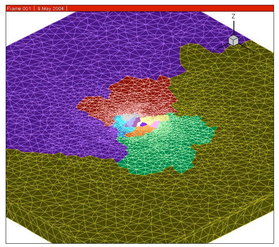
A community faulted-crust model using PYRAMID on cluster platforms

Earth Science Technology Office Computational Technologies Project

Jay Parker, Gregory Lyzenga, Charles Norton, Edwin Tisdale, Andrea Donnellan
California Institute of Technology/Jet Propulsion Laboratory

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California





GeoFEST

Input and Initialization
.dat [Input Mesh]

Initialization Phase ⟷ Partitioning [MPI]

Elastic Problem
- FE K matrix element-wise fill
- RHS assembly

PCG Interative Solve ⟷ Pairwise-Exchange [MPI]
- Local A * v
- Globalize [communication]
- Local dot products
- Global Reduce [MPI]

Time Stepping
- K' matrix element-wise fill ⟷ Pairwise-Exchange [MPI]
- RHS assembly
- PCG Iterative Solve
- Etc…

Output ⟷ Serialization
Ordered data file of element stresses and node displacements

PYRAMID

Input and Initialization [MPI]
.dat.jpl file [Extended Input Mesh]

Recent development has boosted the GeoFEST system for simulating the faulted crust from a local desktop research application to a community model deployed on advanced cluster platforms, including an Apple G5, Intel P4, SGI Altix 3000, and HP Itaniam 2 clusters. GeoFEST uses unstructured tetrahedral meshes to follow details of stress evolution, fault slip, and plastic/elastic processes in quake-prone inhomogeneous regions, like Los Angeles. This makes it ideal for interpreting GPS and radar measurements of deformation.

To remake GeoFEST as a high-performance community code, essential new features are Web accessibility, scalable performance on popular clusters, and parallel adaptive mesh refinement (PAMR). While GeoFEST source is available for free download, a web portal environment is also supported. Users can work entirely within a web browser from problem definition to results animation, using tools like a database of faults, meshing, GeoFEST, and visualization.

For scalable deployment, GeoFEST now relies on the PYRAMID library. The direct solver was rewritten as an iterative method, using PYRAMID's support for partitioning. Analysis determined that scaling is most sensitive to solver communication required at the domain boundaries. Direct pairwise exchange proved successful (linear), while a binary tree method involving all domains was not. On current Intel clusters with Myrinet the application has insignificant communication overhead for problems down to ~1000s of elements per processor. Over one million elements run well on 64 processors.

Initial tests using PYRAMID for the PAMR (essential for regional simulations) and a strain-energy metric produce quality meshes.

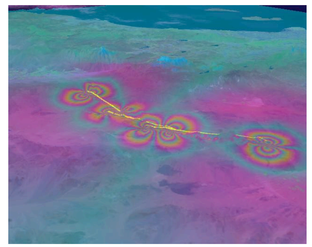
Elastic equilibrium $\sigma_{ij,j} + f_i = 0,$

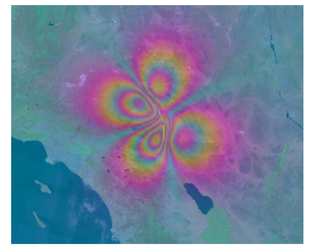
Viscoelastic relaxation $\frac{\partial \sigma_{ij}}{\partial t} = c_{ijkl}\left(\frac{\partial \varepsilon_{kl}}{\partial t} - \frac{\partial \varepsilon_{kl}^{p}}{\partial t}\right)$

Isotropic material $c_{ijkl} = \lambda(x)\left(\delta_{ik}\delta_{jl} + \delta_{il}\delta_{jk}\right) + \mu(x)\delta_{ij}\delta_{kl},$

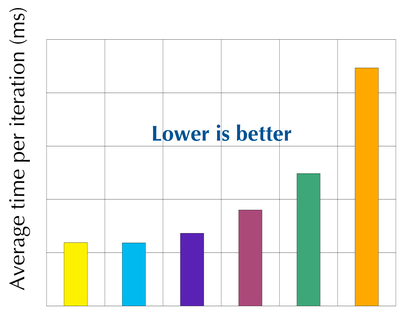
Viscoplastic strain rate $\frac{\partial \varepsilon_{ij}^{p}}{\partial t} = \lambda_{ij}\left(\sigma_{ij}\right),$

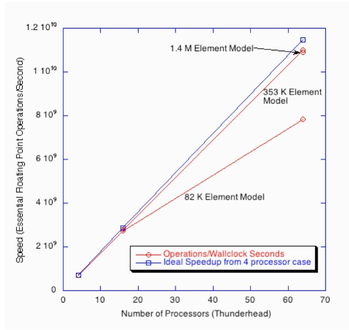
. . . so materials have lame parameters, viscosity, and body force





Simulated 1992 Landers earthquake uplift (left, coded as radar fringes) and post-seismic uplift due to 500 year viscous relaxation (right).





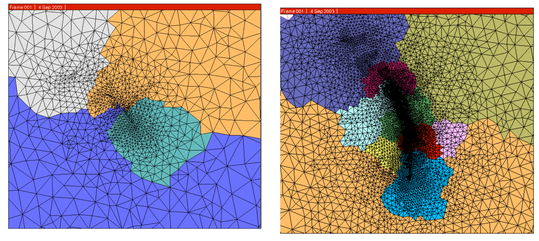
- Apple 2.0 GHz PPC G5 (Infiniband)
- Intel 3.0 GHz Pentium IV (GigE)
- Intel 2.4 GHz Pentium Xeon (Myrinet)
- SGI 1.5 GHz Altix 3000 (NUMA)
- HP 1.0 GHz Itanium 2 (QsNET)
- Apple 1.0 GHz PPC G4 (GigE)

Special Features:

- Source code in C (GeoFEST) and F90 (PYRAMID) is available for download
- Web portal environment (Apache-based) supplies remote tools for meshing, simulation, and visualization.
- Automated parallel mesh refinement (PYRAMID, using a strain-energy metric) in progress

QuakeSim project website
http://quakesim.jpl.nasa.gov/

Increasing mesh densities and partitions . . .



. . . yield increasingly smooth uplift fields